Project ID # VAN022

Connected and Automated Vehicles

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2017 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

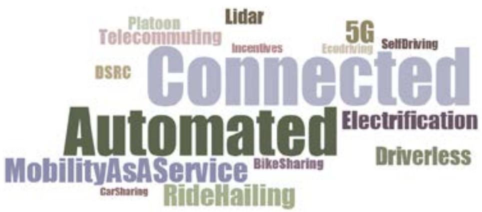
June 8, 2017

Project Overview

Timeline	Barriers
• Project start date : FY17 • Project end date : FY19 • Percent complete : 20%	• Bring technologies to market faster • Integrate a diverse set of simulation tools • Accelerate technology evaluation
Budget	**Partners**
• FY17 Funding : $1471K	• George Mason University (Sub) • University of Illinois in Chicago (Sub) • Texas A&M University (Sub) • UNSW Sydney (Sub) • National Laboratories (LBNL, ORNL, NREL, INL)

Project Relevance

Emerging mobility and transportation solutions



→ **Different traveler behavior**

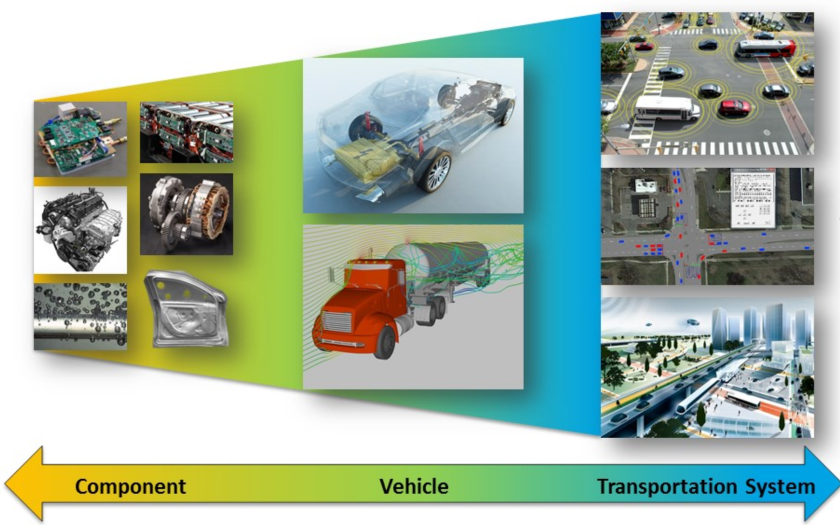
→ **Different vehicle operations**

→ **Energy impact uncertain**

-60% ▬▬▬ +200%

ΔEnergy

VTO is Expanding Focus to the Transportation System Level



Argonne New Capabilities Support New VTO Focus

AUTONOMIE

Single Vehicle
- Eco-driving
- Eco-Routing
- Predictive Control

Multi-vehicle framework / Micro-simulation

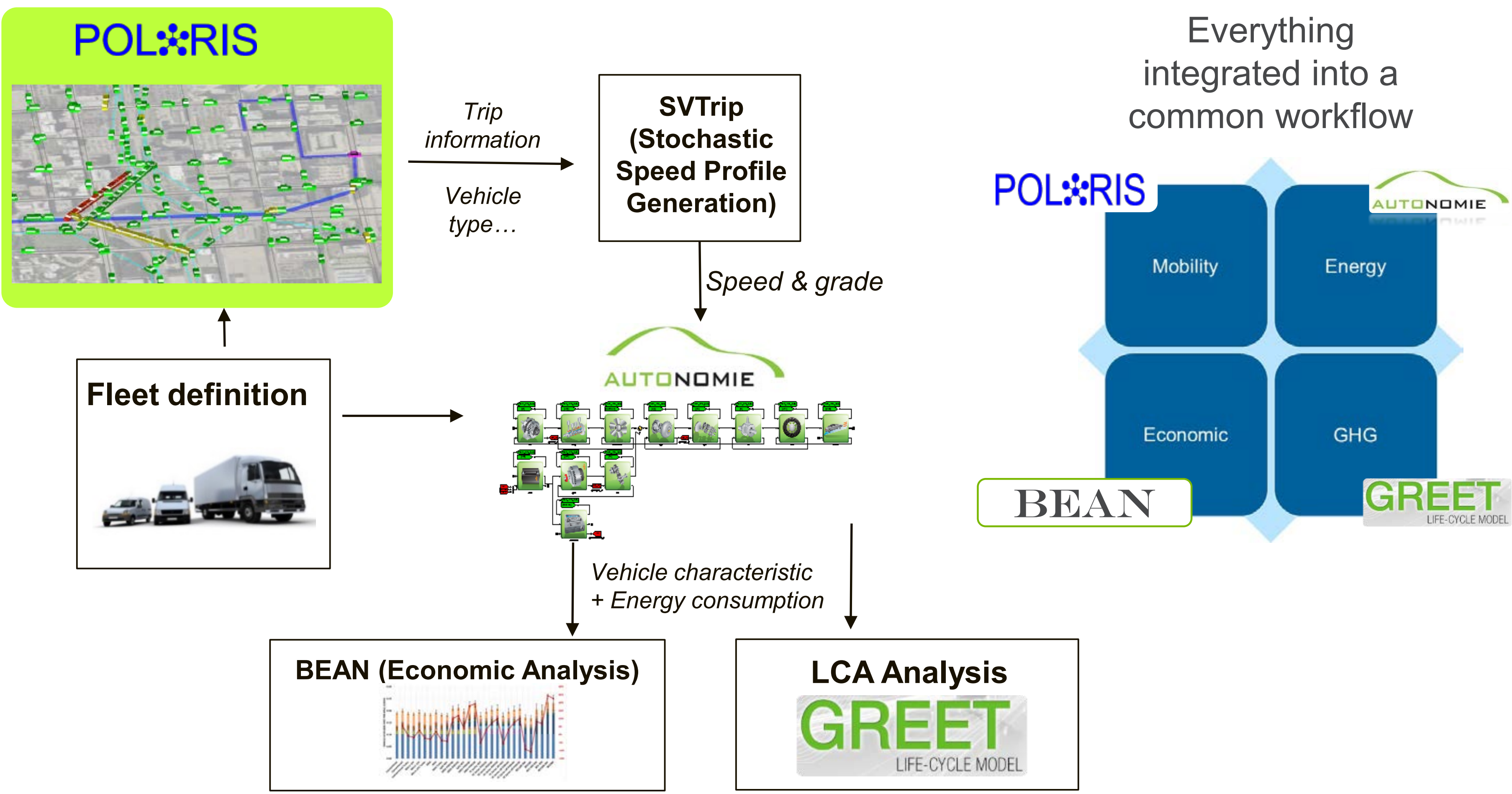
Small Network
- Connected Intersections
- V2X
- ACC, CACC & Platooning

POLARIS

Entire Urban Area
- Connected Intersections
- Platooning & Eco-lanes
- Low-emission zones
- VMT changes

Approach

A Workflow Is Being Developed to Estimate the Energy Consumption, Cost and GHG Impact of Smart Mobility at the Metropolitan Area



Approach

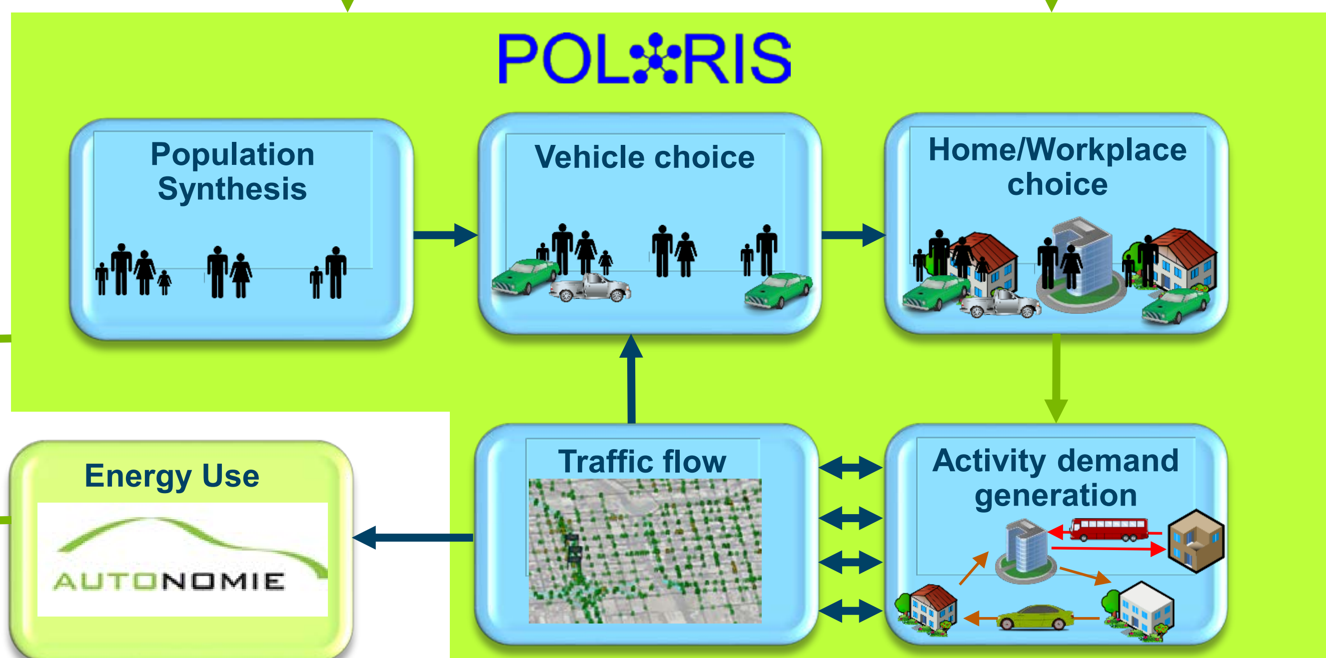
POLARIS Models the Transportation System of Entire Metro Area

Input Data

Travel surveys
Employment data
Transp. network
Vehicle registrations
Land use, …

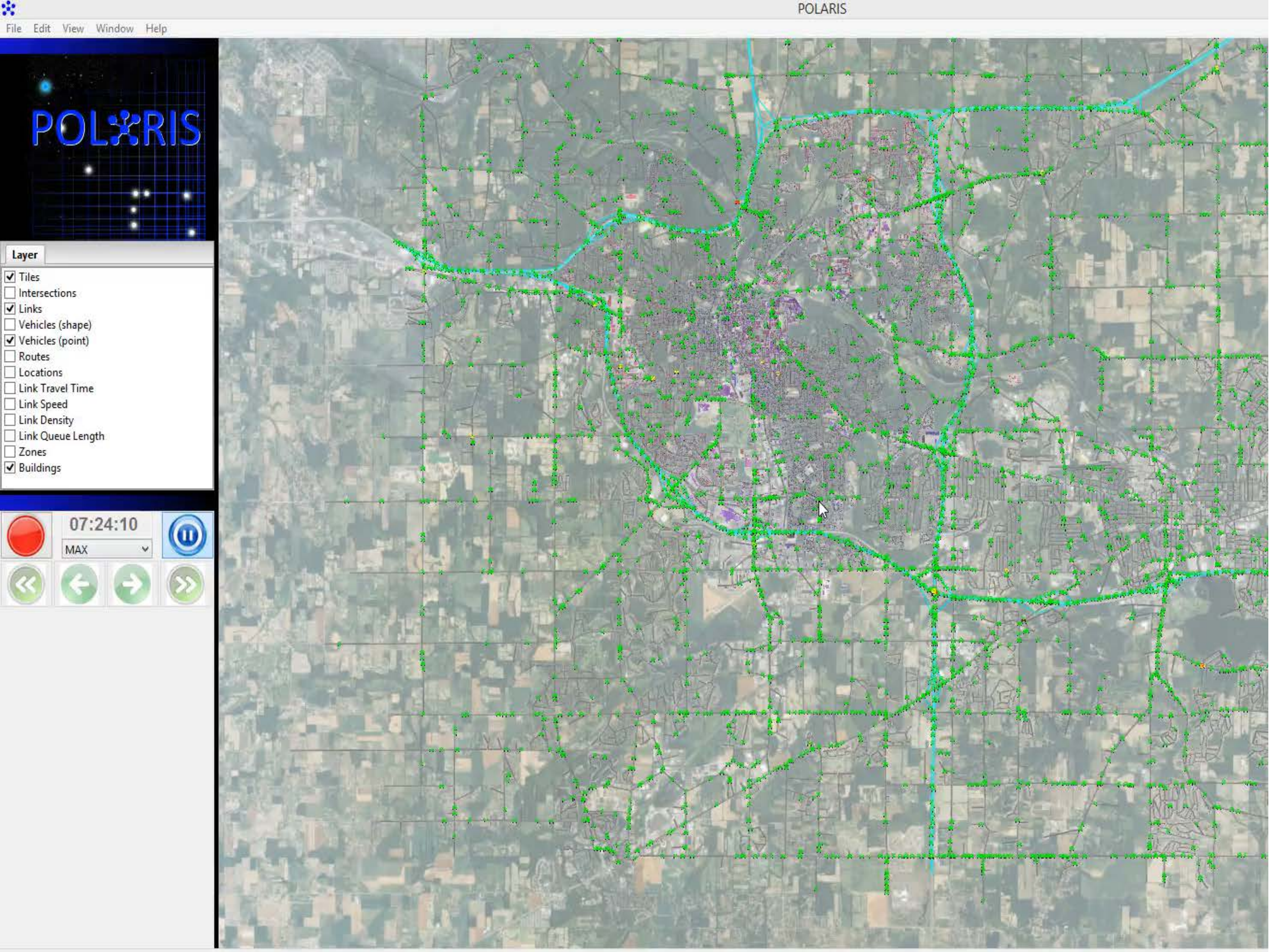
Forecast Scenarios

Infrastructure improvements
Population growth
Demographic shifts
New technologies
Policy environment



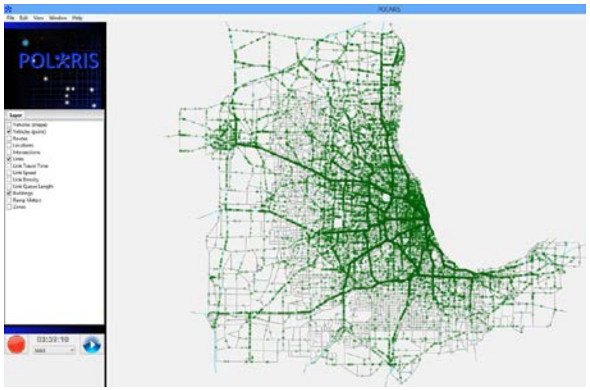
Results

Energy consumption
VMTs
Travel times, …


POLARIS
File
Edit
View
Window
Help
POLARIS
Layer
Tiles
Intersections
Links
Vehicles (shape)
Vehicles (point)
Routes
Locations
Link Travel Time
Link Speed
Link Density
Link Queue Length
Zones
Buildings
07:24:10
MAX

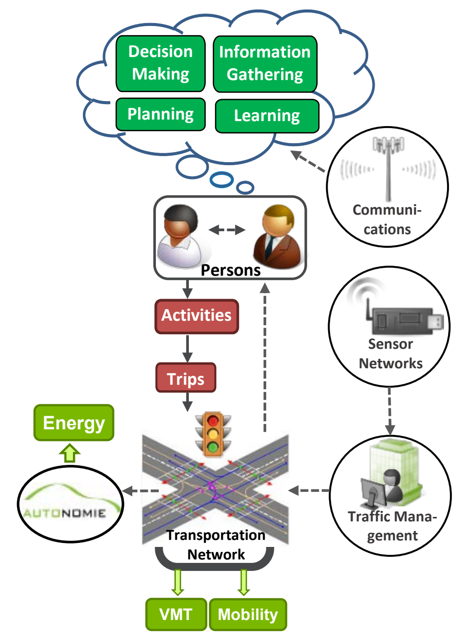
Approach

POLARIS Is Uniquely Designed to Study Energy-Efficient Mobility Systems (EEMS)



- POLARIS is designed for **large-scale studies**:
  - Written in C++, multi-threading
  - Chicago model ≈ 10M travelers ≈ 30M trips (per day) ≈ 3h simulation time (vs. several days for other tools)
- POLARIS is **open-source**, with a dedicated team of developers and transportation experts at Argonne

- POLARIS is designed from the ground-up to accommodate emerging modes and transportation technologies and evaluate their energy-impact:
  - ***Agent-based****: each traveler is modeled individually, has specific behavior and adjust behavior to transportation supply*
  - ***Activity-based****: travel demand is derived from modeled activities (work, school, leisure, etc.)*
  - ***Integrated****:* ***demand*** *(e.g. origin/destination) and* ***supply*** *(routing, traffic flow) are* ***integrated*** *in the same platform, allowing direct interactions (e.g. replanning/rerouting in case of unusual travel time)*
  - ***Energy****: POLARIS + Autonomie outputs energy consumption in the context of evolving vehicle powertrain technologies*

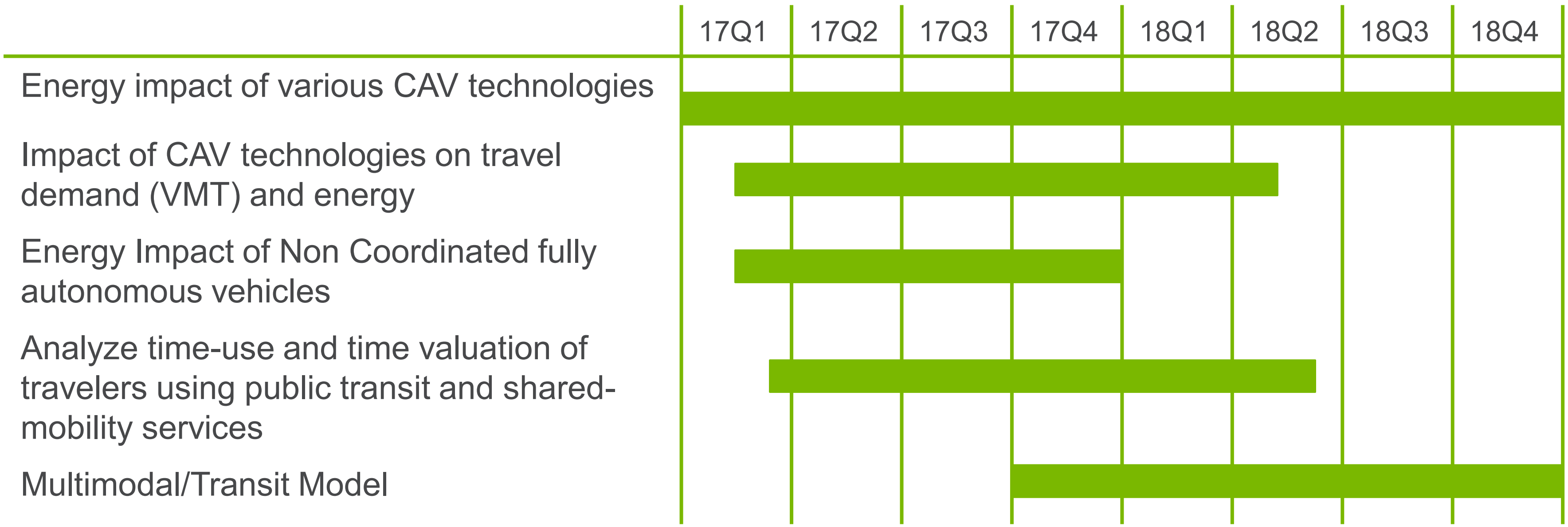


Approach

- POLARIS & Autonomie support research across DOE's SMART Pillars:
  - CAV: how CAVs will change demand and improve operations (EEMS002)
  - MDS: modeling how people will travel in the context of new mobility solutions (EEMS005)
  - MM: how public transit will interact with other modes (EEMS004)
  - Urban => Development of fast calibration to be able to create POLARIS models for other cities more easily (EEMS006)
- Our team is multidisciplinary, combining mechanical, electrical and control engineering as well as behavior science, operations research, energy modeling, computer science and software engineering

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

Milestones

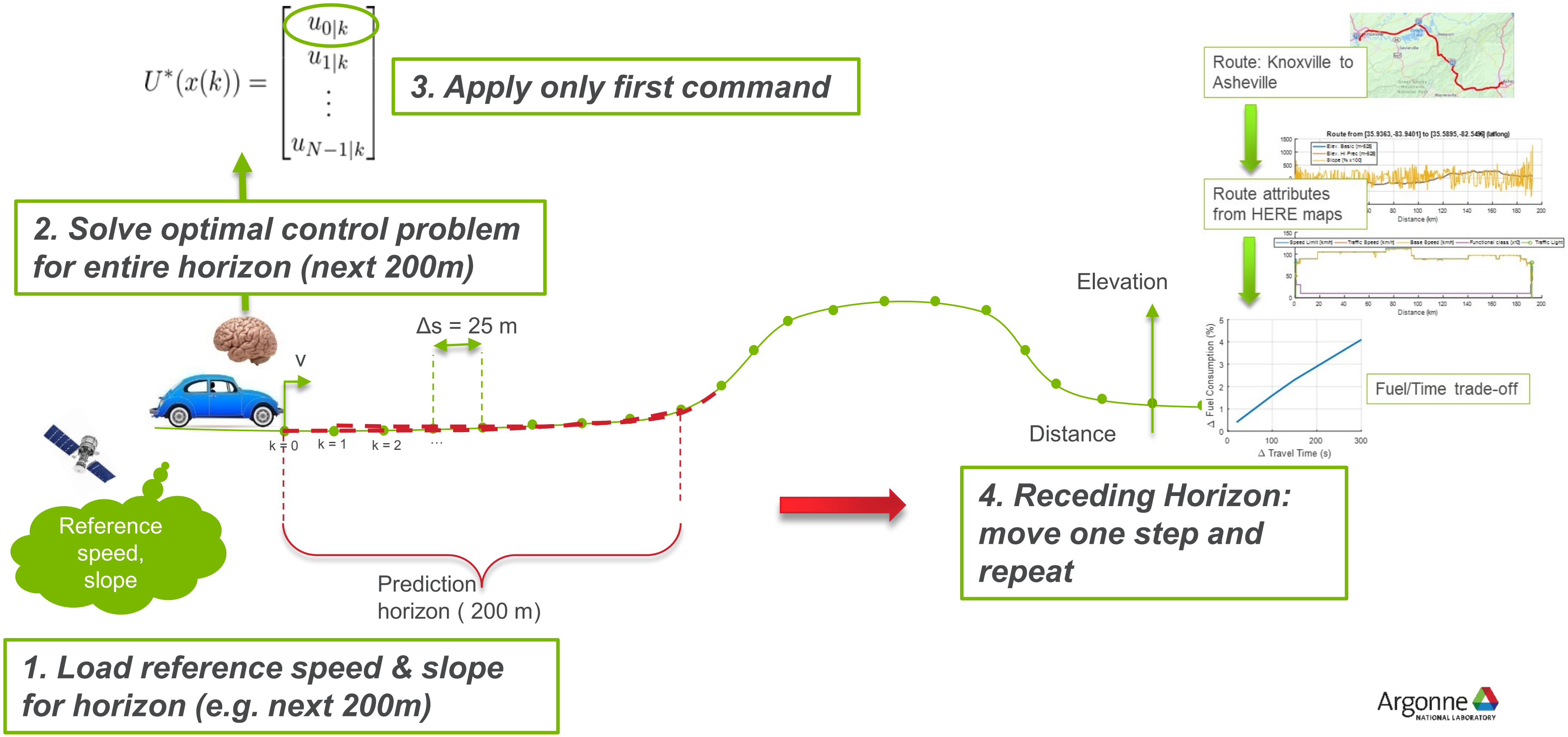

17Q1
17Q2
17Q3
17Q4
18Q1
18Q2
18Q3
18Q4
Energy impact of various CAV technologies
Impact of CAV technologies on travel demand (VMT) and energy
Energy Impact of Non Coordinated fully autonomous vehicles
Analyze time-use and time valuation of travelers using public transit and shared-mobility services
Multimodal/Transit Model

Technical Accomplishments

Implementation-Oriented Control: Model-Predictive Control (MPC)

- MPC is a framework for taking into account continuous look-ahead information for making optimal control decision, while including a feedback-loop (receding horizon)
- Very efficient when model is linear or quadratic => develop quadratic models for conventional vehicle
- Scenario: optimal torque for highway cruise-control => what optimal torque?

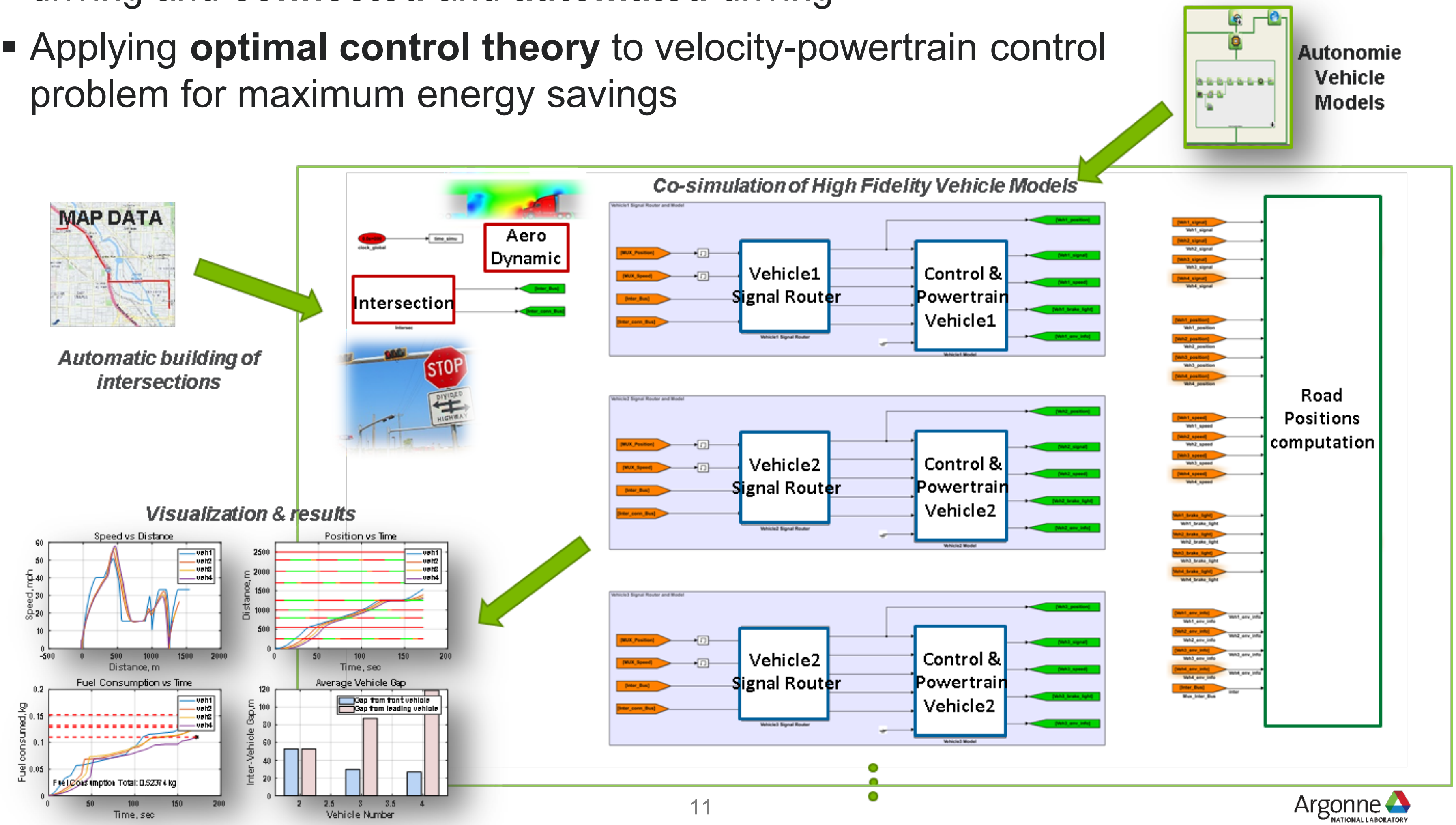
$$U^*(x(k)) = \begin{bmatrix} u_{0|k} \\ u_{1|k} \\ \vdots \\ u_{N-1|k} \end{bmatrix}$$



Technical Accomplishments

Framework for Integrated Powertrain-CAV Simulation

- Developed a Simulink-based framework that reuses **Autonomie** powertrain models and includes models of **intersections**, **human** driving and **connected** and **automated** driving
- Applying **optimal control theory** to velocity-powertrain control problem for maximum energy savings



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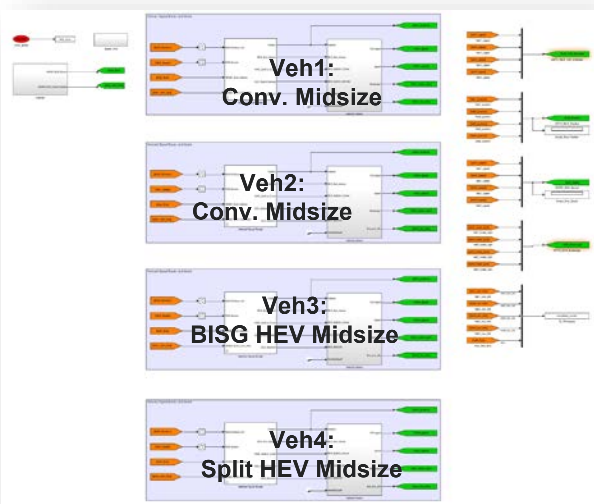
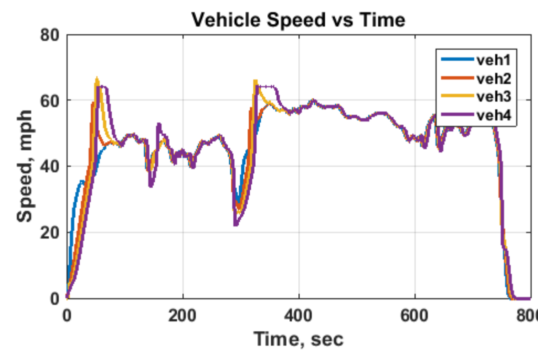
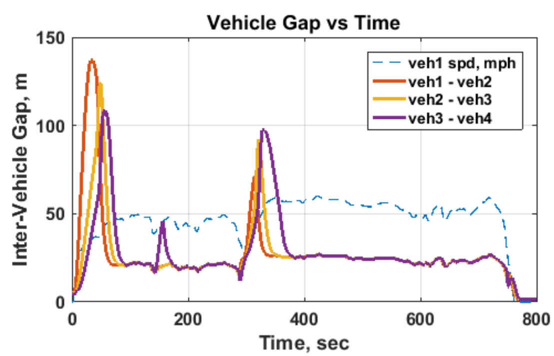
Technical Accomplishments

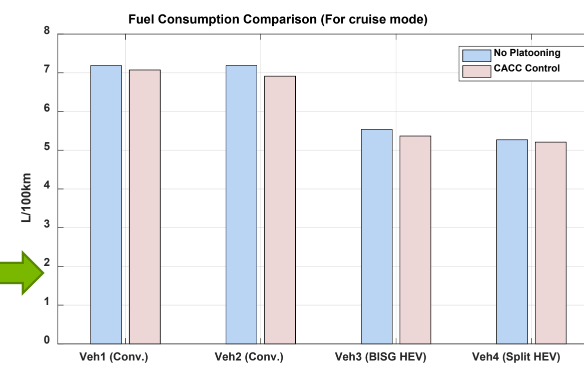
Use Case Example: Highway CACC with Various Powertrains

- Multi-vehicle run with a mix of powertrain technologies
- Lead vehicle follow EPA Highway drive cycle
- Following vehicles are “human-driven” at low-speeds, and switch to CACC above 40 mph
- Each vehicle aerodynamic drag is reduced as a function of gap (and speed?)









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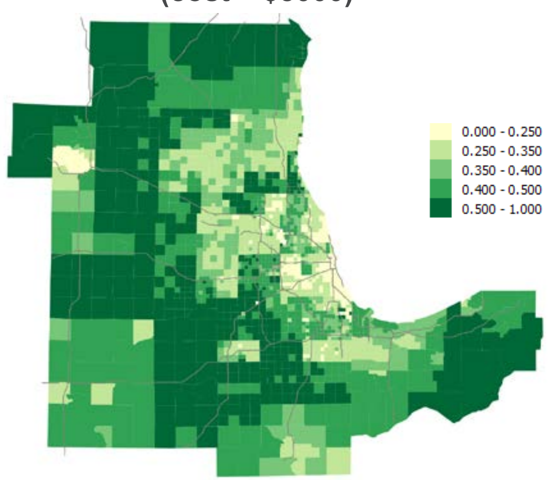
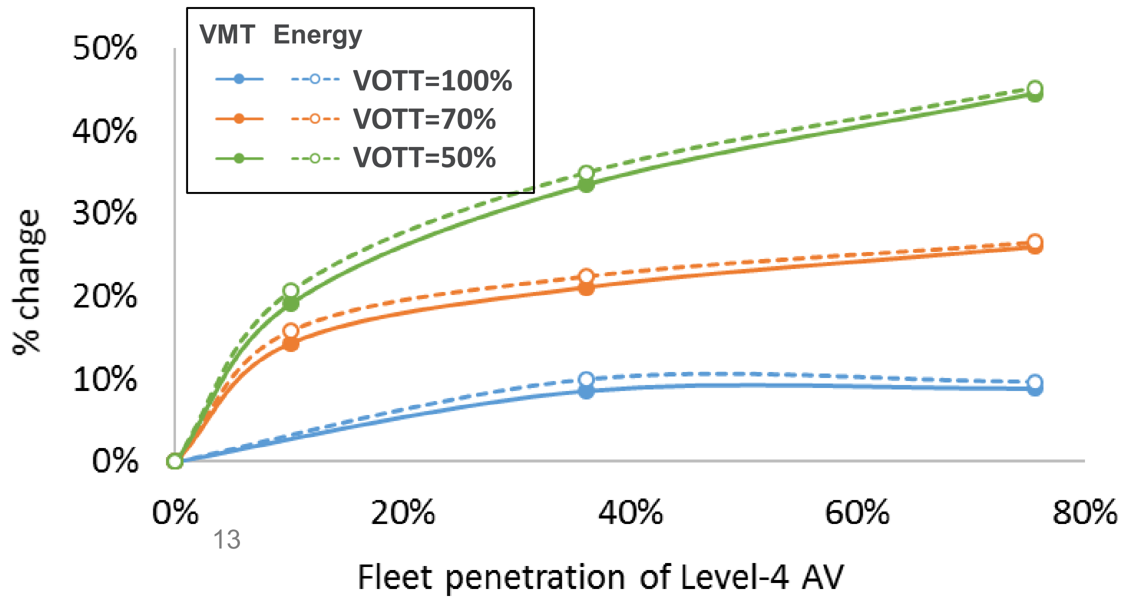
Technical Accomplishments

Evaluated Impact of CAVs on Travel Demand at the Regional Level

- Approach: model the impact of CAVs on both demand and operations
- Improved **POLARIS behavior** and **traffic flow** models:
  - Vehicle-choice model to assign CAVs to particular households
  - Various scenarios for Value of Travel Time (VOTT) based on literature review
- Updated traffic flow model to dynamically change each segment capacity based on the number of CAV present on that link
- Performed a **case study** for Chicago metro area, with 30% and 50% reduction of VOTT, and CAV penetration levels up to 75%; **up to 40% fuel consumption increase** due to higher VMTs
- Larger reduction of VOTT increases fuel use due to longer trips

Level 4 geographic distribution (cost = $5000)

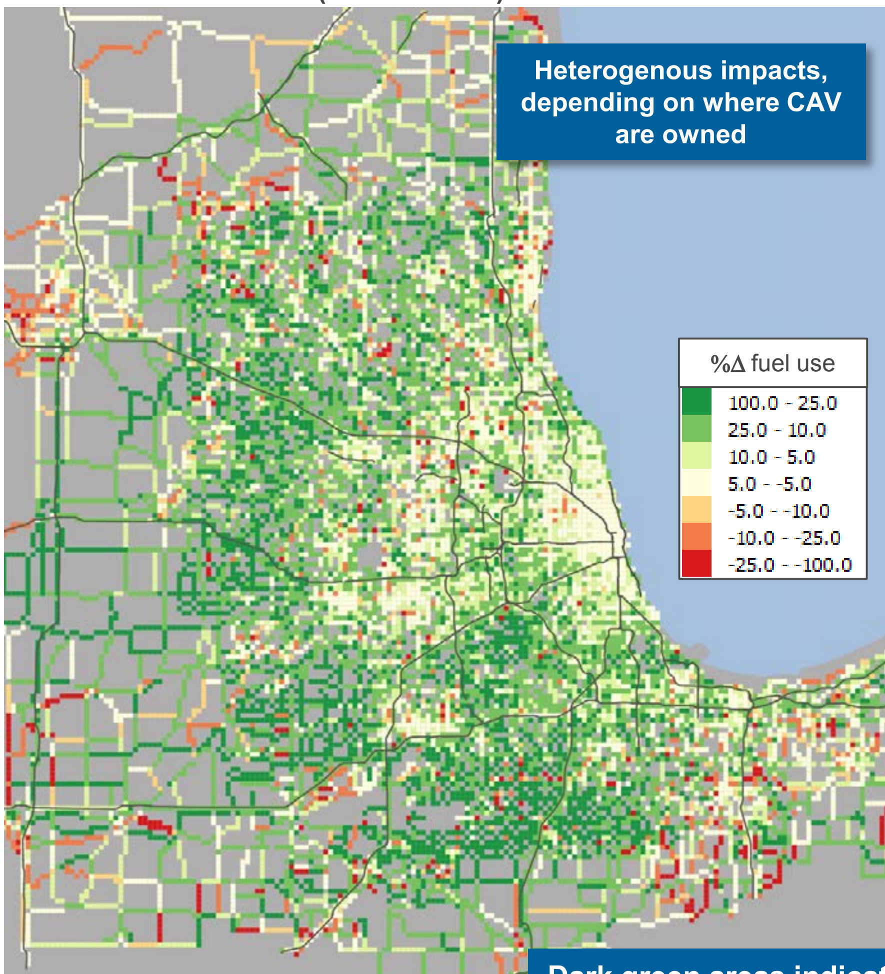




Technical Accomplishments

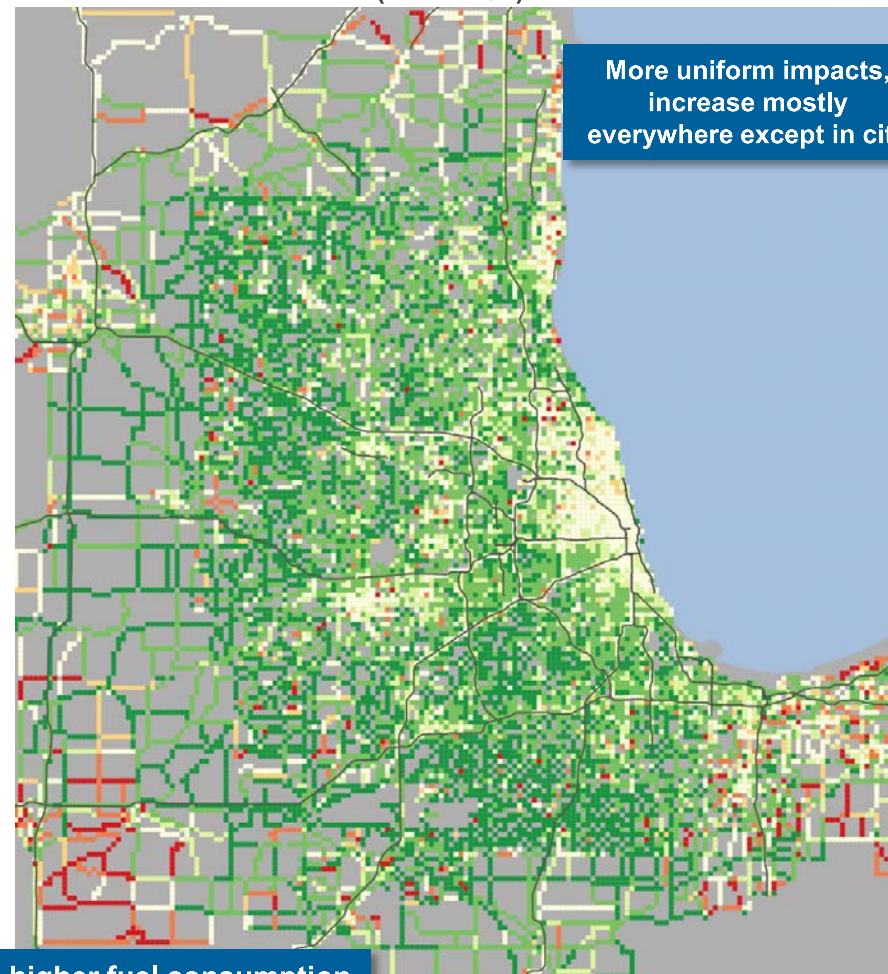
Geographic Distribution of Fuel Use Changes

Difference in fuel use between cost $0 vs cost $15000 (VOTT = 70%)



Heterogenous impacts, depending on where CAV are owned

Difference in fuel use: VOTT 50% vs VOTT 70% (Cost = $0)

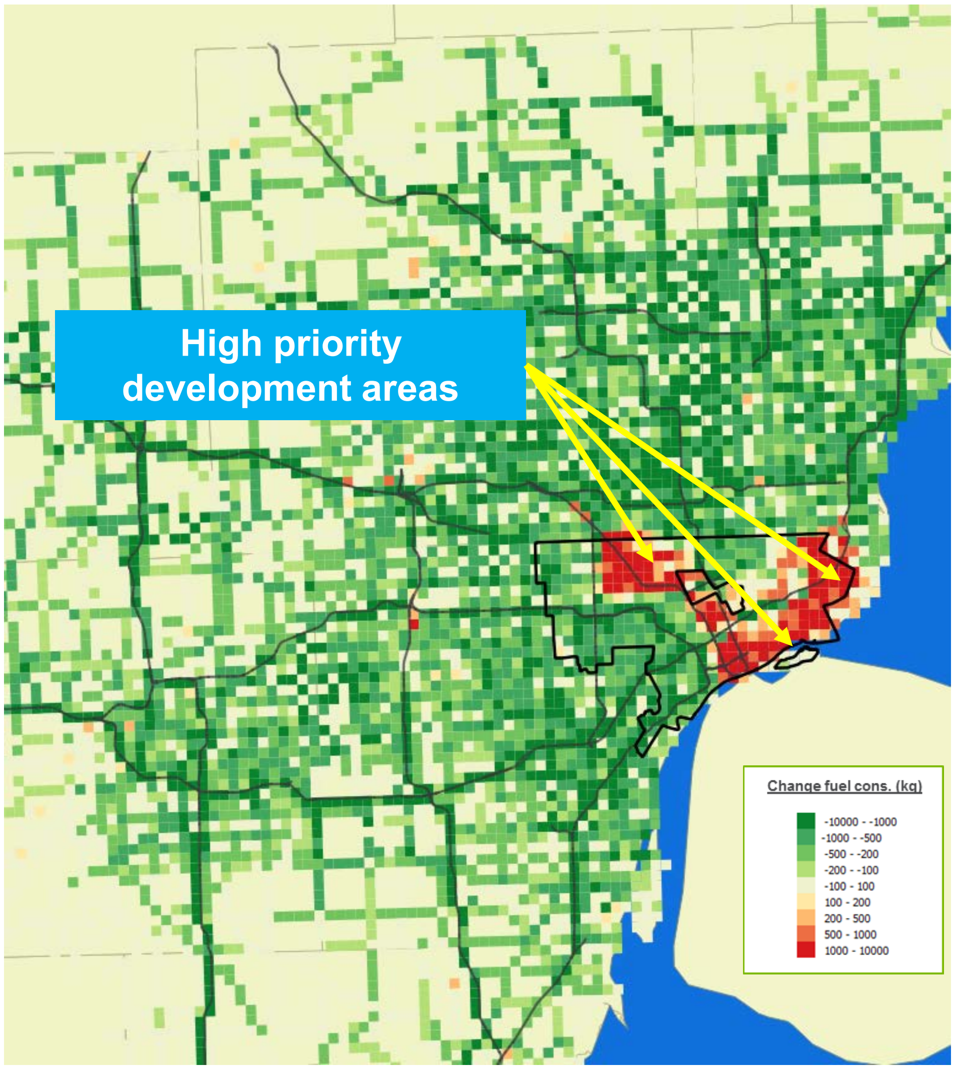


More uniform impacts, increase mostly everywhere except in city

Dark green areas indicate higher fuel consumption for the Cost=$0 or VOTT=50% cases

Technical Accomplishments

Effect of Population Change on Energy for Detroit



Energy consumption per 1km X 1km grid cell

Substantial shifts in energy use seen when comparing SEMCOG to DFC forecast – results for 2010 vehicle technology

Energy Use Results (gallons)				
	Polaris Vehicle Distribution		Regional Vehicle Distribution	
Scenario	2010 Veh	2040 Veh	2010 Veh	2040 Veh
Baseline (2010)	2,121,869	--	2,122,007	--
SEMCOG 2040	2,199,718	1,497,056	2,198,298	1,574,894
DFC 2040	1,952,492	1,329,740	1,951,156	1,329,518
%change				
SEMCOG - Base	3.7%	-29.4%	3.6%	-25.8%
DFC - Base	-8.0%	-37.3%	-8.1%	-37.3%
DFC - SEMCOG	-11.2%	-11.2%	-11.2%	-15.6%

Response to Previous Year Reviewers' Comments

Project was not reviewed in the past

Partnerships and Collaborations

Federal Transit Administration

cta Chicago Transit Authority

TARDEC

CMAP Chicago Metropolitan Agency for Planning

M | MTC

AUBURN UNIVERSITY

GEORGE MASON UNIVERSITY

Connected Signals

Carnegie Mellon University

A M

UIC

TSINGHUA UNIVERSITY 1911

WASHINGTON STATE UNIVERSITY

ifp Energies nouvelles

UNSW THE UNIVERSITY OF NEW SOUTH WALES

MICHIGAN

Remaining Challenges and Barriers

- Travel behavior modeling of current and future modes is highly uncertain
- Need multiple data sets (e.g., travel surveys are expensive) to develop better models, especially behavior models need data, often from surveys
- Energy benefits is highly dependent of scenarios. Defining and selecting appropriate scenarios while maintaining acceptable computational time is challenging
- Developing processes leveraging HPC is a requirements: even if POLARIS runs the entire Chicago population in 2-3h vs 2-3 days for other models, running hundreds of simulations to quantify the uncertainty is challenging
- Transferability needs to be improved as developing POLARIS models of new cities is expensive, both for data gathering, processing and calibration

Future Work

- POLARIS:
  - Traffic flow model will be improved to more realistically represent the movement of CAVs on the road
  - New model of Zero Occupancy vehicles (ZOVs)
  - New behavioral model for activity-generation, scheduling, mode-choice
  - Connect to vehicle choice modeling for realistic fleet distribution
  - Transferability for national level energy evaluations
  - New modes: transit, bike, TNCs
- CAV control:
  - Integrate new framework with Autonomie eco-system
  - Improve human driver models
  - Implement CAV controllers with optimal control for advanced powertrain technology vehicles
- Deploy new tools and processes with AMBER

Any proposed future work is subject to change based on funding levels

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Summary

- Emerging mobility trends, such as CAVs, will result in profound changes in the way people make their travel choices and the way vehicle operate
- There is a wide uncertainty about energy impacts, and DOE VTO EEMS initiative aims at better estimation
- Key achievements:
  - Performed preliminary study estimating energy benefits of CAVs using drive cycle filtering
  - Developed a new framework for Integrated Powertrain-CAV Simulation
  - Initiated work on energy-efficient CAVs using optimal control
  - Improved POLARIS to model CAVs:
    - Traffic flow model: congestion reduction due to increased capacity
    - Value of travel time reduced for owners of CAVs
    - Model of vehicle CAV choice
- Future work will focus on developing new CAV controls, new modes, new behavior models, improving traffic flow models and running large-scale case studies to estimate energy impact of CAVs.